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A SPIN AND DEPLOYMENT MECHANISM

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ABSTRACT

The spin ejector was developed as a simple and reliable mechanism to spin and deploy small payloads from an earth orbiting platform. It is one component of a complete system for retaining a payload during vehicle ascent, releasing the payload for deployment, deploying the payload, and securing the payload canister after deployment. The complete system was designed, fabricated and qualified for flight in just over one year, with the flight article delivered to the launch site in October, 1987. This paper will briefly describe the complete system, and then focus on the deployment mechanism (spin ejector) design concept and test program.

INTRODUCTION

The system described herein was designed to retain, release, spin and deploy four payloads from the canister cluster assembly (see Figure 1). Each payload, retained in individual payload canisters and cradles (see Figures 2 thru 4), weighed less than 400 pounds and was to be deployed at a predetermined spin rate and a velocity of 3 meters per second (9.84 feet per second, ±10 percent). The spin ejector (see Figures 5 thru 8) was chosen as the deployment mechanism over design concepts utilizing two independent systems (one for spin and one for deployment with motors, controls, batteries, etc.) because of its relative simplicity and reliability. A compact pneumatic system utilizing high pressure helium controlled through an orifice was chosen to power the deployment in order to minimize weight. Because of the amount of new hardware, an extensive development and qualification test program was required to prove the system for flight.

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SYSTEM DESCRIPTION

The body of the system is the payload canister assembly (see Figures 2 and 3). Its major components are the cover, latch, cradle, pneumatic system, spin ejector, and closer mechanism. For this specific mission the canister had to be atmospherically sealed, requiring a vent system to be incorporated in the design. Both the vent and pneumatic system are operated by redundant normally closed ordnance valves. The latch release is initiated by redundant ordnance pin pullers. Torsion springs open the cover after latch release. The spin ejector mechanism, functioned by release of the source pressure and controlled by an orifice, deploys the payload. The cover closer mechanism closes the cover using residual pressure from the spin ejector after piston stroke.

Each payload is supported within the canister by four pins located in the cradle retainers and two pins located in the cover. These pins are preloaded against the payload to support it from the time of vehicle launch to deployment.

DEPLOYMENT SEQUENCE

Listed below is the deployment sequence (see Figures 4 and 5) -

- 400 seconds prior to deployment the ordnance vent valve is fired, allowing the trapped atmosphere to leave the canister (vacuum is achieved in approximately 350 seconds)

- 20 seconds prior to deployment the ordnance pin pullers are fired allowing the latch to release. Torsion springs are assisted by the cover pins (preloaded against the payload) in opening the cover, leaving the payload supported by the four cradle retainer pins. The cover rebounds and comes to rest in approximately 7 seconds against the stop.

- Deployment is initiated by functioning the ordnance valve, releasing source pressure into the spin ejector cylinder. The piston drives the lead shaft and cradle, accelerating the payload. When the piston reaches its stop (approximately 0.070 seconds) the payload is moving at its required deployment conditions.

- The lead shaft withdraws from the piston allowing the cradle to follow the payload. Springs help to retract the cradle retainers in the expanding cone area of the canister, releasing the payload and allowing it to fly free. The retainers contact the cradle stop (approximately 0.022 seconds after piston stop), stopping and retaining the cradle.

- The cover closer mechanism receives residual pressure from the spin ejector, closing the cover approximately 10 seconds after piston stop. Spring plungers lock the cover closed. A separate orifice and plenum retard the pressure going to the closer mechanism, allowing time for the payload to clear the cover prior to its closing.

CANISTER DESCRIPTION

The canister assembly (see Figures 2 and 3) consists of three machined rings connected by 1.27 mm (0.050 inch) riveted sheet metal. The bottom ring provides an attach point for the spin ejector mechanism. The middle ring, which connects the conical and cylindrical sheet metal sections, contains these integrally machined features; a cradle support shelf, spin up cylinder, payload release expanding cone, and cradle stop. The forward ring is machined with a precision diameter chamfer to mate with an o-ring in the cover and form an atmospheric seal. Additionally, this forward ring includes a mounting flange used to attach the canister to the cluster bulkhead.

The shelf in the lower half of the middle ring supports the cradle and payload prior to launch and during ascent. Above the shelf is a cylindrical bore which holds the retainers against the payload during acceleration. The first 5.0 cm (2.0 inch) of this cylinder is machined with a precision diameter required to hold the retainer pins at the desired preload. During deployment, the retainers move quickly past this precision diameter and roll on a slightly larger bore. The majority of the linear and rotational acceleration occurs within the 11.7 cm (4.6 inch) constant diameter section.

The retainer rollers are at the cylinder/cone intersection and the payload is fully accelerated when the piston reaches its stop. The retainers then retract into the expanding cone, allowing the retainers and preload pins to rotate away from the payload. After the pins are fully disengaged from the payload, the retainers contact the stop located at the top of the cone. This action stops and retains the cradle within the canister while the payload flies free.

CRADLE/RETAINER DESCRIPTION

Each canister contains a cradle assembly (see Figure 3). The cradle assembly consists of a lead shaft, a 1.27 mm (0.050 inch) aluminum sheet metal cone connecting two machined rings, and four cradle retainers containing rollers and preload pins. The cradle transfers the linear and rotational acceleration forces from the spin ejector piston to the payload.

Mounted to the cradle's top ring are four retainer assemblies. Two self aligning rollers on the outside of each retainer guide it along the canister cylindrical section during payload acceleration. These are aligned with the lead shaft helix to eliminate sliding. The preload pins are threaded into bushings press fit into the retainers. Threading permits easy pin adjustment for accurate preloading and centering of the payload within the cradle. This preloading operation occurs in a simulated canister middle section prior to payload installation into the canister.

Each preload pin has a spherically tipped surface which engages a conical receptor of the payload. The pins are mounted in a threaded bushing containing a series of belleville washers. The belleville washers create a compact, high spring-rate suspension system to support the payload against launch and ascent loads.

SPIN EJECTOR DESCRIPTION

The spin ejector (see Figures 5 thru 8) consists of a pneumatic piston/cylinder assembly which drives the lead shaft. The shaft is machined with opposing helical tracks which bear against rollers fixed to the drive plate mounted at the cylinder top. Therefore, as the piston translates the shaft, the shaft must rotate. The helical tracks are cut at the appropriate lead angle to cause the shaft to rotate at the desired spin rate when it is translated at the required velocity.

The radius to the center-line of the lead shaft helix is made large (3.18 cm/1.25 inch) to reduce the force on the rollers (normal to the helical track) generated by the accelerating payload's rotational moment of inertia. Because of the magnitude of these loads, it is critical that each of the rollers contact the lead shaft equally (creating a balanced spin-up couple). To provide for this, laminated shim stock (0.05 mm/0.002 inch laminations) positions both rollers radially and tangentially (see Figure 7). This adjustment provides a method to accurately center the shaft within the bushing, and reduce forces between the shaft and bushing.

The bushing is positioned close to the rollers in order to react system unbalances without creating large moments. It is made of 17-7 corrosion resistant steel and lined with a Teflon impregnated fabric liner; the lead shaft mating diameter is hard anodized. These materials and finishes were chosen because of the low friction between them. Cutouts machined in the bushing allowed it to be positioned near the rollers (see Figure 8). Flats on the bushing keep it from rotating and binding a roller.

A thrust bearing in the piston bears on the lead shaft to permit free relative rotation. The bearing is lubricated with a vacuum compatible perflourinated polyether-based lubricant. This proved to be a satisfactory lubricant; however, it did not prevent the bearings non-cadmium coated surfaces from corroding. This required the bearings unprotected surfaces to be painted with a corrosion resistant primer.

Because one atmosphere of pressure is trapped under the piston after the canister is vented in orbit, detent assemblies are required to retain the piston and cradle/payload assembly prior to deployment (see Figure 9). These are fixed to the drive plate and mated to a ring on the top of the lead shaft. The detent plunger and ring are fabricated from steel to withstand the high contact stresses. The plunger is heat treated to a slightly lower level than the ring to permit a custom fit of the two parts.

Because the detents retain the piston and cradle/payload assembly prior to deployment, the helium flow is allowed to develop before the cylinder volume begins to expand. Also, the detent assemblies, in combination with a leaf spring acting on the piston bottom, keep the lead shaft and piston in contact. This prevents any chance of impact damage due to gapping.

To stop the piston, a Shore 90 polyurethane rubber pad is used. Its reusability for the development and qualification test program made it preferable over crush blocks.

PNEUMATIC SYSTEM DESCRIPTION

The pneumatic system used to power the deployment consists of a source pressure bottle, ordnance activated isolation valves, corrosion resistant steel tubing, and a control orifice. The 885 cc (54 cubic inch) source, pressurized to 5.0 MPa (725 psi), is controlled by sharp edged orifices ranging in diameters from 0.193 cm (0.076 inch) to 0.320 cm (0.126 inch). Varying the orifice size permits equal pressurization of each system, thus eliminating the possibility of incorrect pressurization of the canisters. These parameters create choked flow at the orifice throughout the piston stroke, thus greatly simplifying the gas flow analysis and minimizing the upstream line losses. The relatively large orifice diameters eliminated the need for a filter in the system.

Limited space dictated the spin ejector base be designed with the pneumatic input at the side. Because positioning the control orifice at the base inlet (for easy inspection) would create a second choke point in the gas flow, it is located on the mounting surface of the base (cylinder inlet). This simplified the pneumatic analysis but made orifice size verification more difficult.

The residual pressure in the spin ejector cylinder is released to the cover stop and closer mechanism (see Figures 2 and 4) after the power stroke. This mechanism, which stops the cover on its opening, utilizes a small pneumatic cylinder to close the cover. A 1.5 mm (0.060 inch) diameter hole in the spin ejector cylinders wall allows the pressure to exit without causing damage to the piston seal. The pressure is controlled by a 0.25 mm (0.010 inch) diameter orifice and 283 cubic centimeter (17.3 cubic inch) plenum in route to the cover stop and closer cylinder. This delays the cover closer cylinder action until the payload clears the cover. Two spring loaded plunger assemblies lock the cover closer mechanism in the closed position so it can not retract as the pressure is lost.

Weight was not a major concern during the system development. This became a favorable condition for sizing hardware due to uncertainties in predicting the pneumatic response during payload deployment. The complete pneumatic system was designed for a conservatively high operating pressure of 20.7 MPa (3000 psi). The working pressure determined from the development test program was 5.0 MPa (725 psi). The maximum dynamic pressure within the spin ejector was found to be 173 psi. This corresponds to a peak axial force of 16,661 N (3745 lbs) thrust.

ANOMALIES

The initial spin ejector design utilized a self aligning roller bearing to bear against the lead shaft helix. This choice allowed the rollers to align themselves normal to the lead shaft helix during the power stroke. However, during development testing, this roller failed at its loading slots due to excessive normal loading. Marks on the lead shaft helix also indicated high forces present at this interface. Furthermore, the self aligning aspects of this roller created difficulty verifying initial roller alignment with respect to the lead shaft's helical track during payload installation.

The failed bearing was replaced with a crown roller bearing which is designed to roll on a surface. One suitable for the mechanism loading and requiring only a slight shim adjustment was found allowing testing to continue after a two day delay. The new roller proved to be satisfactory; no anomalies were encountered. Additionally, the problem of verifying the initial roller alignment was eliminated.

TESTING

One of the more challenging aspects of this program was testing. Two methods of testing the deployment were devised: one deploying vertically up and one deploying vertically down. The vertical up tests utilized a counter balance and bungee-cord system. The bungee-cord was sized to keep the suspension system tight while the payload was being accelerated at greater than one G. The counter balance was sized to negate the effects of gravity. These tests were used to determine the deployment velocity and corresponding spin rate.

The vertical down technique involved deploying the payload into a capture net. These tests utilized rate gyros to determine the payload cone angle of deployment.

For the upward tests, bar charts attached to the accelerating payload were filmed with high speed cameras to yield deployment velocity. The spin rate was calculated from this linear velocity and lead shaft helix angle (linear and rotational velocities are directly related through the lead shaft helix angle). For the downward tests, rate gyro data yielded the spin rate directly. The velocity at the moment of piston stop could then be calculated from the lead shaft helix.

A pressure transducer was inserted in the spin ejector cylinder to gather dynamic pressure data. This data provided -

- maximum thrust forces within the system used to determine component stress and strength margins.

- data with which the pneumatic model could be matched for verification.

A thermocouple was added to further verify the analytical model. However, the deployment event occurs faster (0.070 seconds) than the thermocouple can react.

CONCLUSIONS

The spin ejector mechanism has proven to be a simple and reliable mechanism for spinning and deploying payloads in space. A thorough test program verified its simplicity and reliability which are attributes required due to the limited development time allowed for this program. The design, which benefits from its adaptability to many payload configurations and deployment conditions, is suitable for both non-space and space uses.

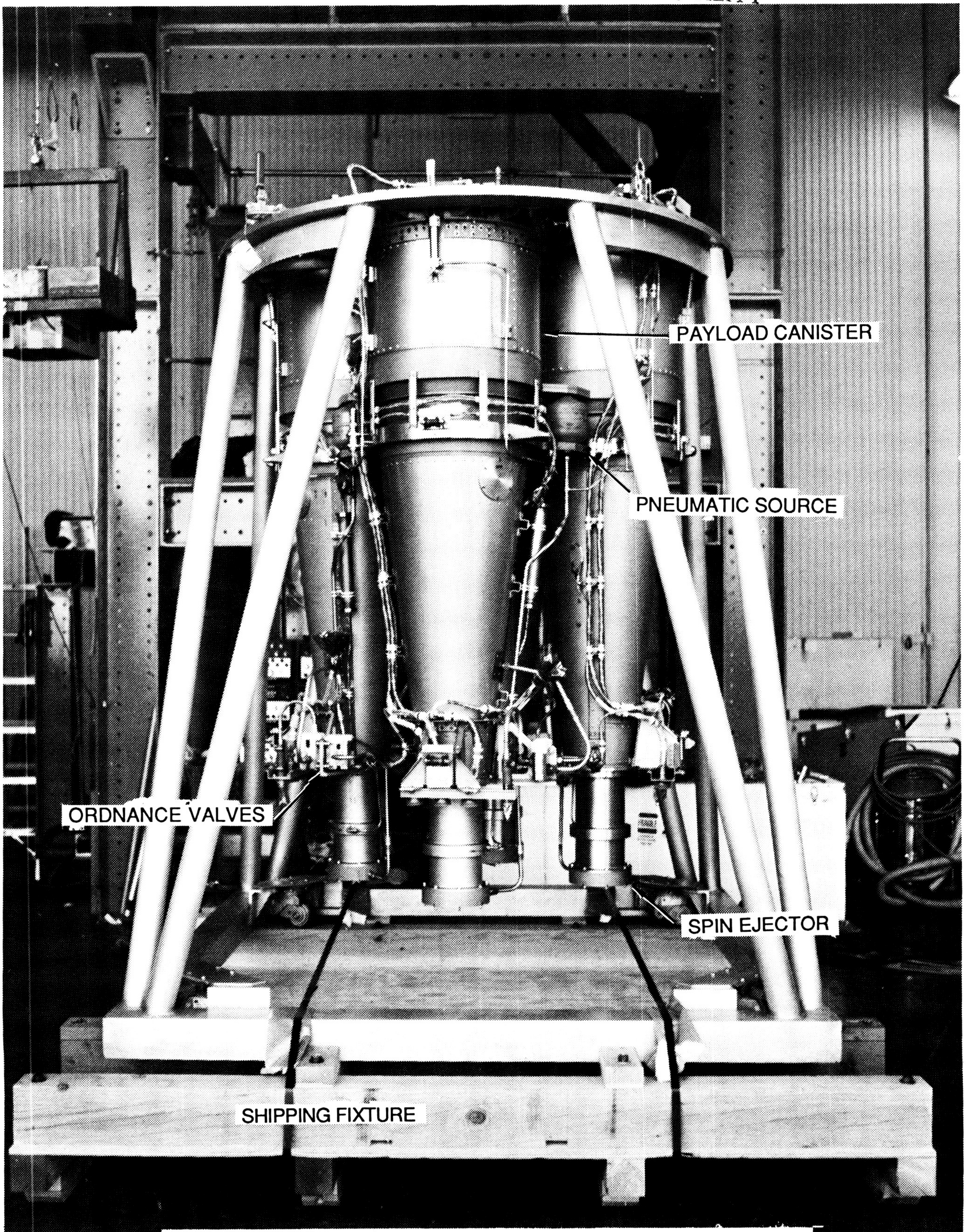

FIGURE 1: CANISTER CLUSTER ASSEMBLY

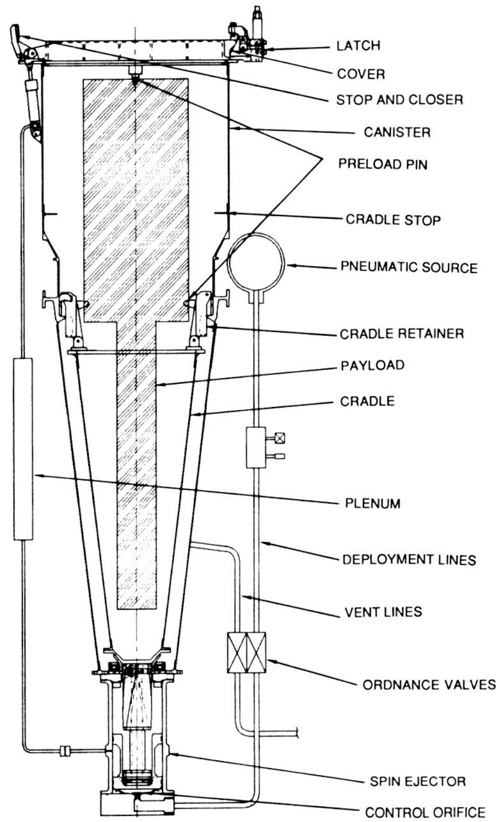

FIGURE 2: CANISTER ASSEMBLY SYSTEM

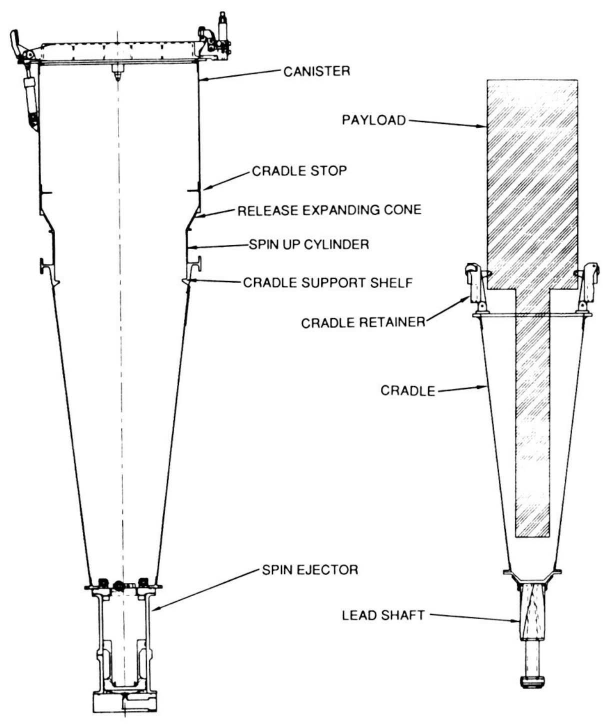

FIGURE 3: CANISTER AND CRADLE SEPARATED

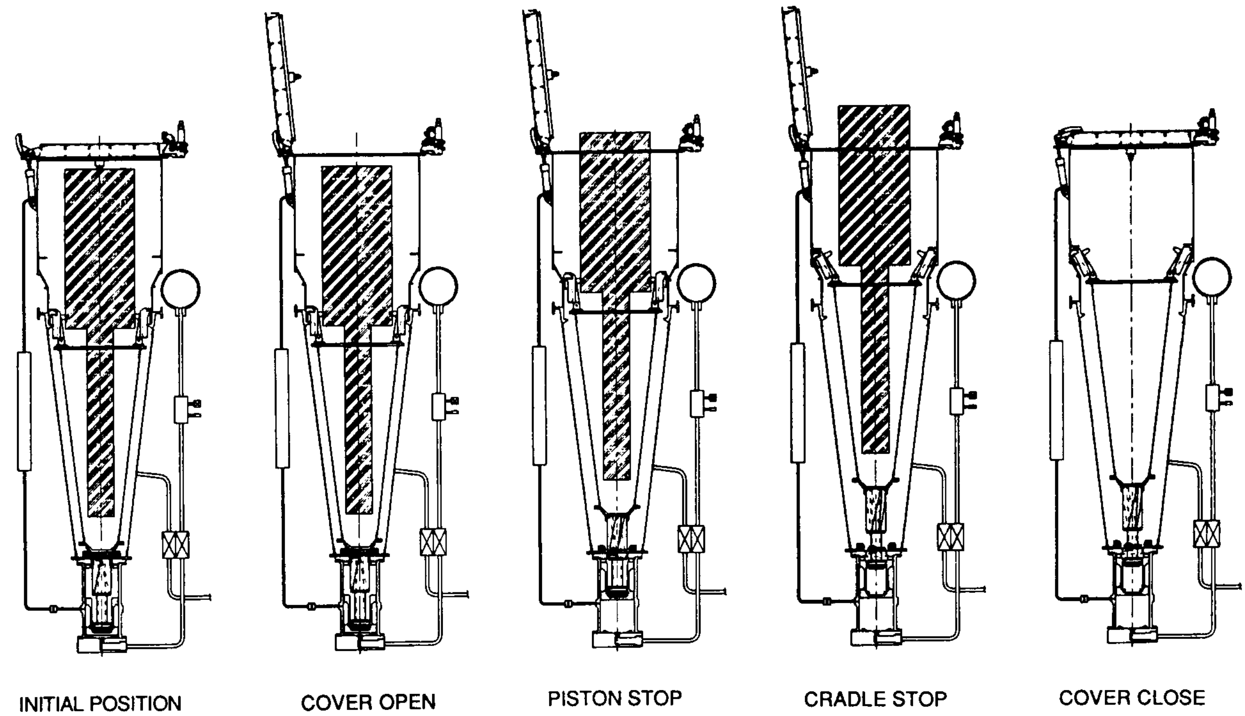

FIGURE 4: CANISTER DEPLOYMENT SEQUENCE

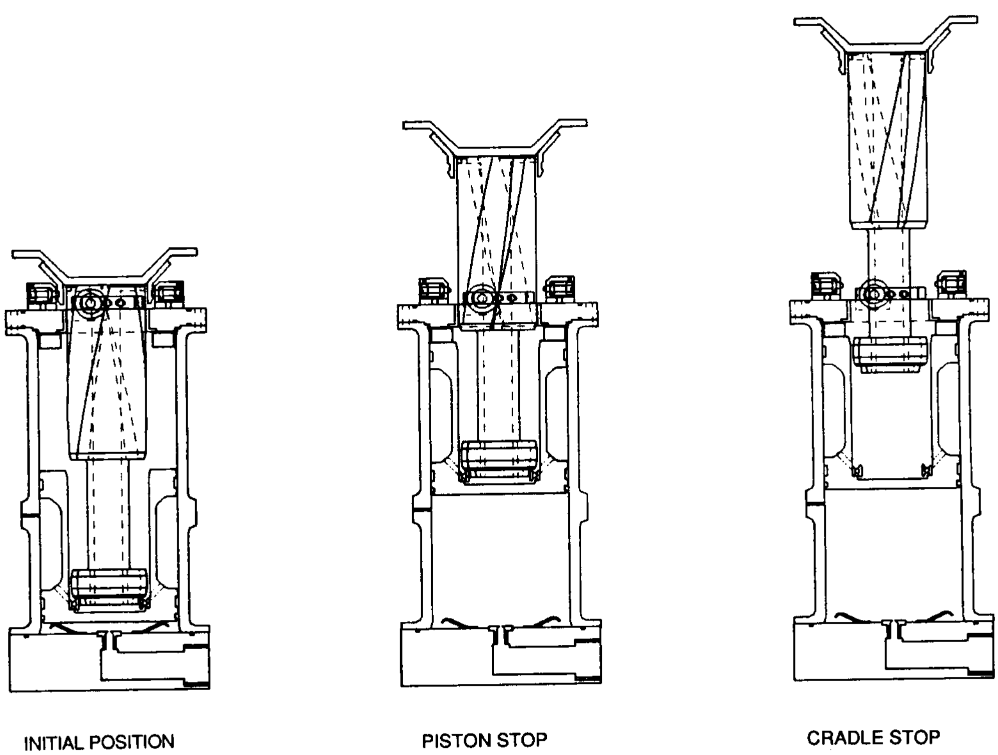

FIGURE 5: SPIN EJECTOR DEPLOYMENT SEQUENCE

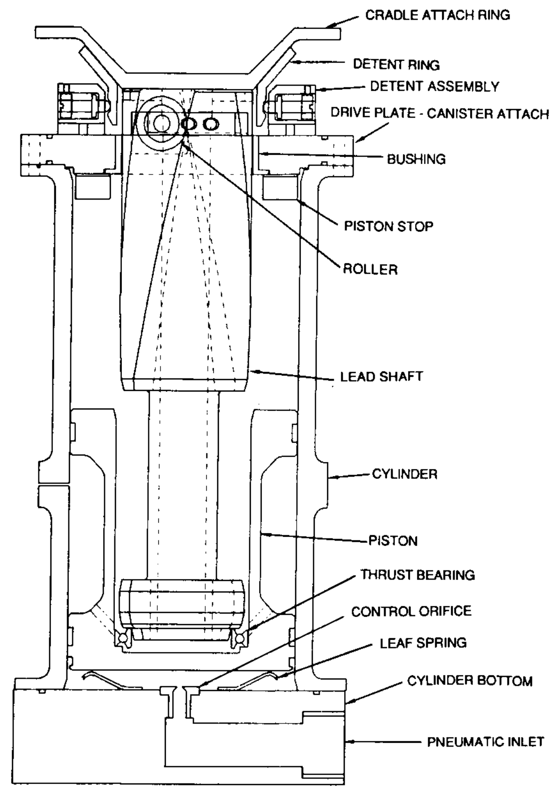

FIGURE 6: SPIN EJECTOR ASSEMBLY

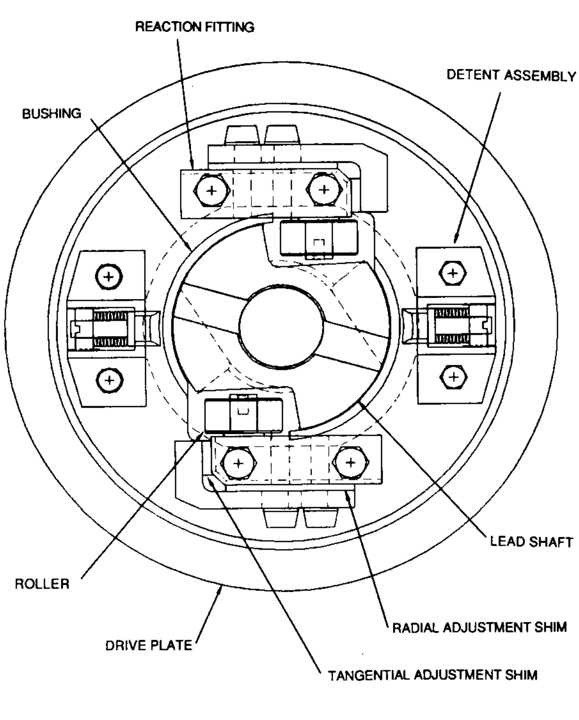

FIGURE 7: SPIN EJECTOR ASSEMBLY - TOP VIEW

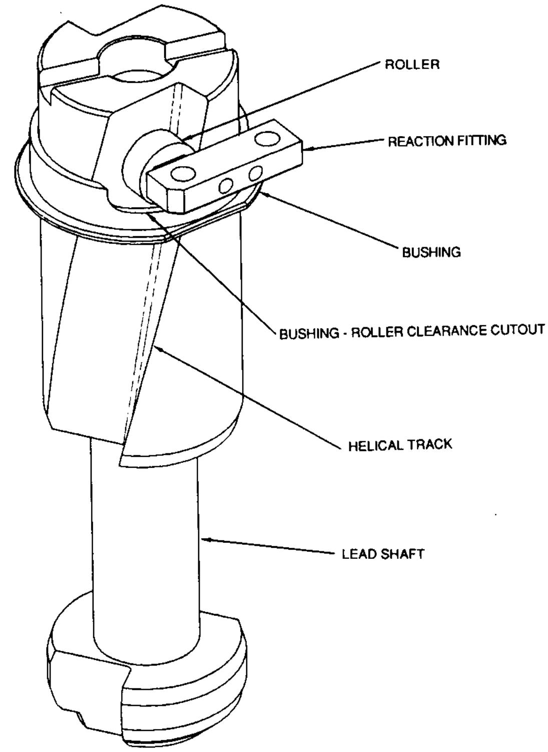

FIGURE 8: LEAD SHAFT - BUSHING - ROLLER ARRANGEMENT

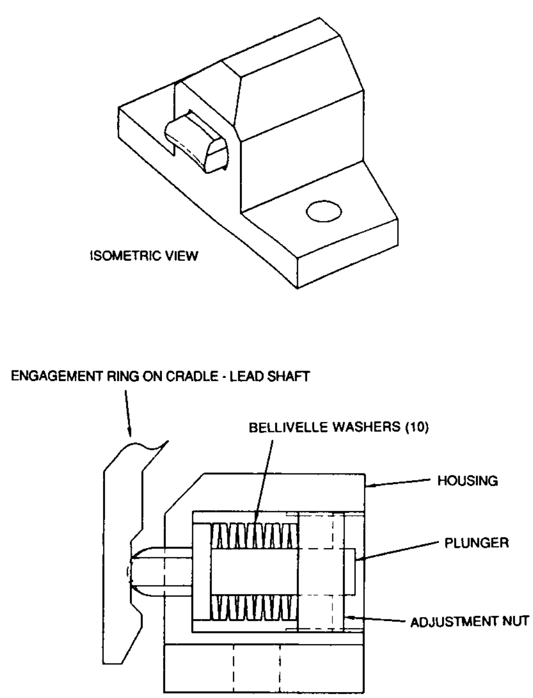

FIGURE 9: DETENT ASSEMBLY DETAIL